The Sublittoral Benthic Fauna and Flora Off Del Monte Beach, Monterey, California

BY

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(3 Plates; 9 Text figures)

INTRODUCTION

Over a period of 26 months, from early January 1971 to late February 1973, an intensive investigation of the fauna and flora of the sublittoral area off Del Monte Beach was carried out by staff and students of the Department of Oceanography, Naval Postgraduate School. The initial stimulus for this investigation came in September 1970 when it was officially announced that a new breakwater system would be built adjacent to the present harbor in Monterey by the U. S. Army Corps of Engineers and some Federal funds were appropriated to initiate the project. This presented an opportunity to make an investigation of a shallow water marine environment, essentially open to the sea, before and after a major breakwater complex was built. In many localities along our coasts harbor construction projects in the past have significantly influenced the ecology of the shallow water marine environment, but these influences were difficult to evaluate, as insufficient study of the area had been made prior to the start of construction. It was our plan to try to obtain fairly complete base line data from the area of the proposed breakwater before actual construction began and then to continue the investigation for several years after completion of the breakwater until some new equilibrium was established. In addition to our primary studies on the identity and distribution of the plants and animals of the area we also made a systematic study of the nature of the sediments and rock outcrops and changes that occur in bottom topography throughout the year in this relatively exposed area. Using a wave recorder with a sensor located in the study area we were able to record wave patterns during part of the study period. In the near-by present harbor area we have a continuous record of sea surface temperature.

In the summer of 1971 a preliminary paper on the ecological implications of breakwater construction in Monterey Harbor was published (Haderlie, 1971). Two theses covering various aspects of this overall study have also been completed (Minter, 1971; Booth, 1972).

As of the spring of 1973 no start had been made on the proposed breakwater, and because of funding problems it seemed unlikely that the new harbor complex would be built for several years. We decided therefore to publish the results of our two years' work. If and when the new breakwater is built, the results of this investigation can be used as a basis for additional studies.

We wish to acknowledge the help of many people. During the course of the investigation a total of 6 cruises were made on the Naval Postgraduate School's hydrographic research vessels for the purpose of collecting bottom sediment samples and the infauna of the soft bottom stations. In addition, the bottom was profiled and sand depth measured using small boats. We wish to thank the Captain and crew of the Research Vessel *Acania* for consistent help and cooperation. Students and staff of the Department of Oceanography also assisted on these cruises. In the intensive study of the transects and stations, over 120 SCUBA dives were made, each dive often involving 3 or more divers. We wish to thank the many student divers from the Naval Postgraduate School for giving up leisure time to dive, often under very difficult conditions, to make this study possible. We are also indebted to Anthony Weaver of Hopkins Marine Station for loan of equipment, and ideas on underwater shale excavations, and to Janine Haderlie for help in the laboratory analyses. For aid in the identification of organisms we thank Drs. Donald P. Abbott and Isabella A. Abbott of Hopkins Marine Station, Dr. Louis S. Kornicker of the National Museum of Natural History, and Dr. William B.

Gladfelter of the California State University, San Diego. The office of Naval Research through the Naval Postgraduate School Foundation Research Program and the Naval Facilities Engineering Command provided financial assistance for part of the project.

AREA of STUDY

Figures 1 and *2* illustrate the existing harbor area in Monterey. The breakwater to the north of the harbor consists of granite rock quarried locally. It was constructed between 1931 and 1934 by the Corps of Engineers and was designed as a permeable breakwater. It has proved effective, except in severe storms, in damping waves and swell coming from the north. This breakwater has given protection to a fishing fleet, two wharfs, and a marina in the inner harbor, but surge in the harbor is still a major problem during storms. For many years the City of Monterey, the local fishing industry, and more recently the owners of pleasure craft have tried to persuade the Corps of Engineers to build a so-called companion breakwater to the east of Municipal Wharf No. 2. This proposed breakwater has taken many forms over the years, but in all plans it was to run from the shore at Del Monte Beach toward the north and northwest to near the end of the present breakwater with only a narrow channel for passage between the two. The area of our study therefore was restricted to the east of Wharf No. 2 which would become enclosed by the proposed breakwater. This site has a gently sloping bottom covered with sand and outcrops of what is commonly called "Monterey Shale." This is really an outcrop within Monterey Bay of the Miocene marine unit known as the Monterey Formation which underlies most of the southern part of the Bay, and for the most part is covered with thick layers of Recent assorted sands and gravels. At the study site the outcrops of Miocene rock is a resistant, brown, silicious mudstone composed mainly of diatomite and diatomaceous shale, interbedded with opaline chert (Green, 1970). The stations selected for detailed study, as outlined below, cover both these soft bottom stretches and the outcrops of the Monterey Formation. The study area includes a large kelp bed and three of the study transects run into this bed.

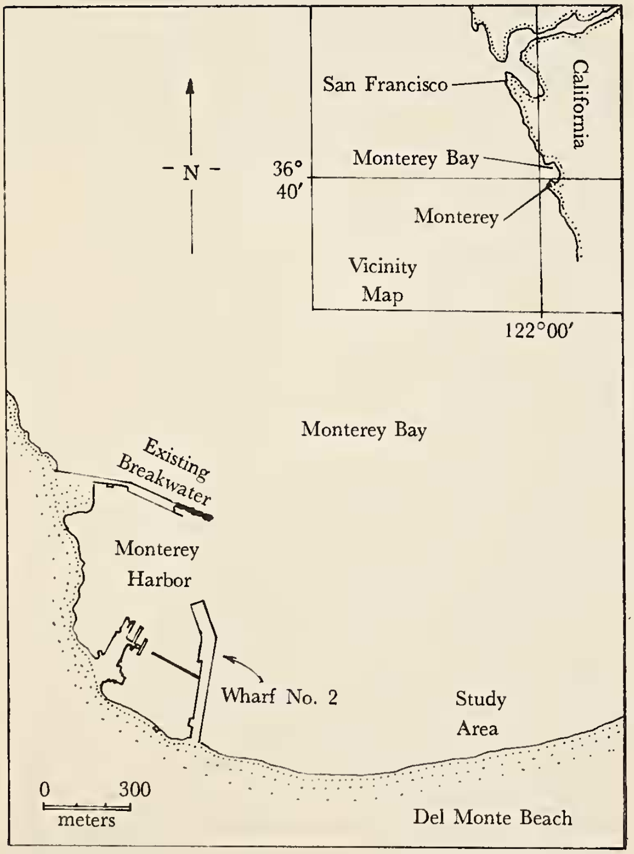


Figure 1

Map showing Location of Study Area

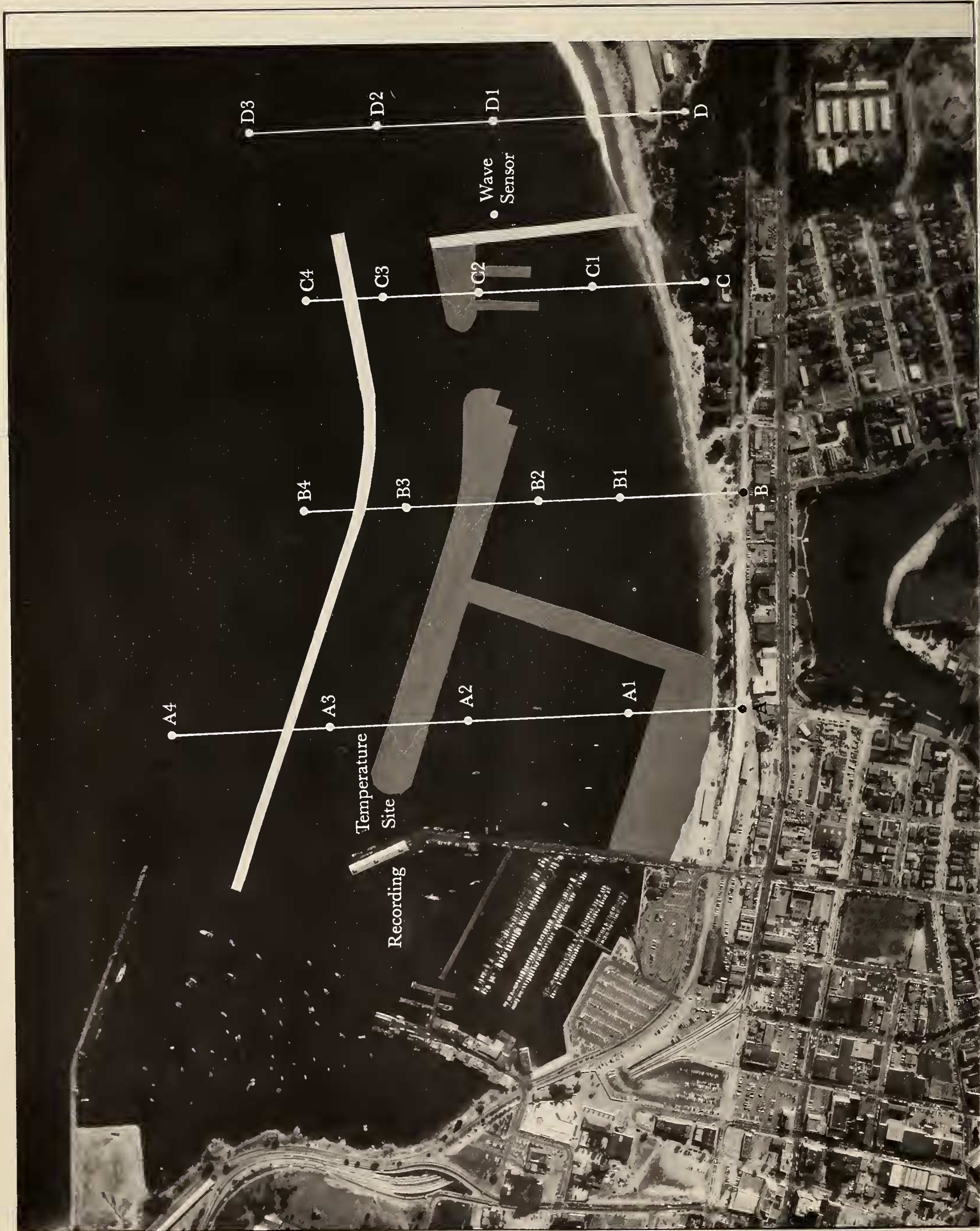
a. Proposed Breakwater Complex

The final plan for the new breakwater adopted by the City of Monterey was one prepared in the late 1960s by Koebig and Koebig Engineers. Figure *3* illustrates the basic plan. The proposal was to construct a new permeable east breakwater and a separate north breakwater of granite blocks (Figure *3*, light shading). East and west channels up to 100 m wide would give access to the inner harbor. This part of the breakwater was to be built first. At a later date several large non-permeable earth- and rock-filled moles (Figure *3*, dark shading) were to be built, and extensive marinas for pleasure craft were to be developed. The plan, as adopted, obviously would have a

Explanation of Figures *2* and *3*

Figure *2*: Aerial photograph of Monterey Harbor and Study Area (17 September 1971, official U. S. Navy photograph by VC-63 Squadron NAS Miramar)

Figure *3*: Aerial photograph with transect and station positions and proposed Breakwater Complex (17 September 1971, official U. S. Navy photograph by VC-63 squadron NAS Miramar)


D3
D2
D1
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Wave Sensor
C4
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B3
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A4
A3
A2
A1
A
Temperature Site
Recording

significant impact on the oceanographic conditions and on the animal and plant populations to be enclosed in the new harbor area (see HADERLIE, 1971).

b. Transect and Station Locations

In January 1971 a series of ecological transects was established across the area of the proposed new harbor to the east of Wharf No. 2 in what is now open water (Figure 4). Along these transects a series of 15 stations was selected in water varying from 2 to 15 m in depth. The transects themselves and the individual stations were positioned in such a way so that if the plan for the proposed new construction was followed none of the stations would be covered, but would remain available for continued studies after construction. Indeed the distal stations on Transects A, B and C were positioned to be outside the proposed new breakwater, and the entire Transect D with its 3 stations was established to be to the east of the proposed construction. The stations outside the area to be "developed" would serve as control sites for observations and study.

To undertake an intensive study of such a small geographic area (approximately 1 km^2) required an extremely accurate means of positioning. Every station had to be occupied repeatedly by boats and SCUBA divers without the aid of radios and electronic navigation equipment. Positioning was done with a repeated accuracy of a few meters and never more than 10 m from each station. This was accomplished by using a set of pre-established intersecting visual range lines.

Transect lines A, B, C, and D (Figures 3 and 4) run from high on the beach to beyond the proposed breakwater. Permanent landmarks, such as telegraph poles or mature trees, were chosen for anchor points on the shoreward end of the 4 transects (Table 1). Temporary secondary markers were installed on a heading of Grid North (or Lambert North = 342° magnetic) approximately 50 - 100 m seaward of the anchor points in order to provide visual range lines for each transect.

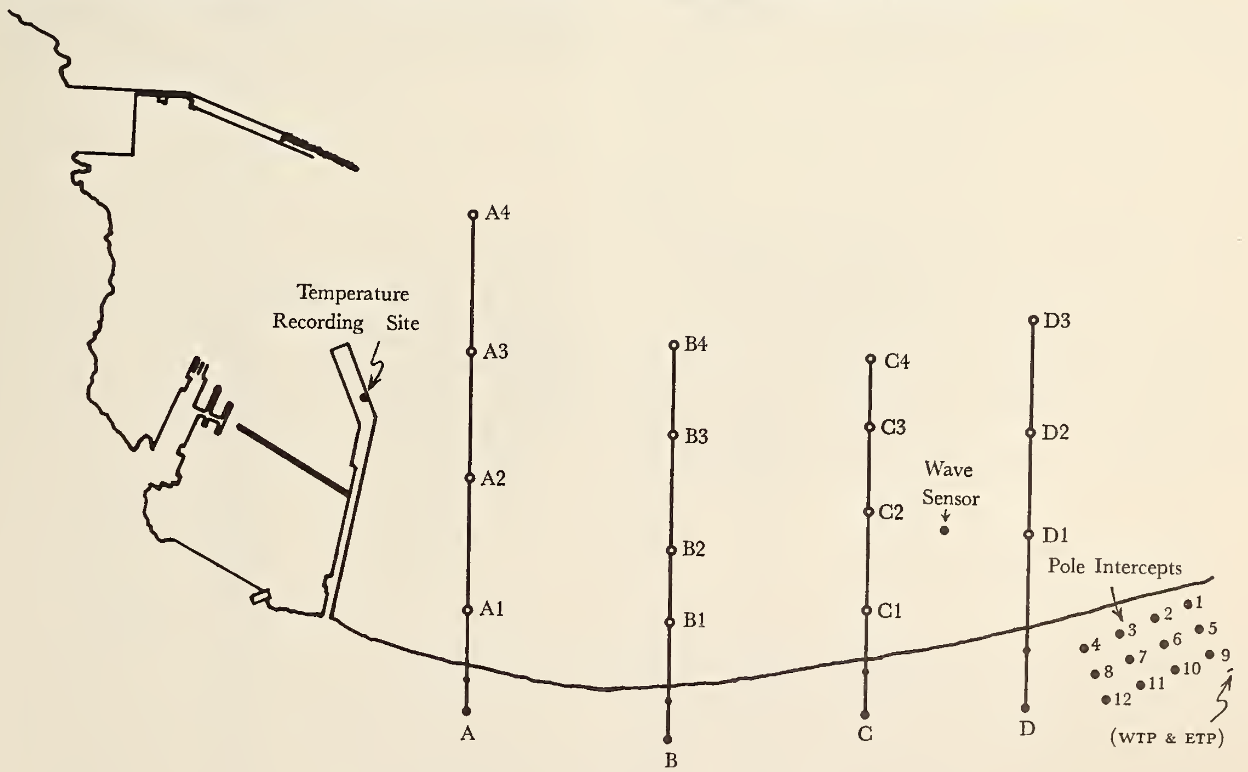


Figure 4

Study Area with Transect, Station, Pole Intercept, and Sensor Locations

Table 1

Location of Transect Anchor Points

Transect Anchor Points	Anchor Point Physical Description	Plane Coordinates Lambert Projection X	Y	Polar Coordinates Geographic Positions Latitude	Longitude
A	Southern Pacific Telegraph Pole with white painted stripe	1 152 928	474 025	36°36′01.81″	121°53′10.01″
B	Southern Pacific Telegraph Pole with white painted stripe	1 153 996	473 967	36°36′01.55″	121°52′56.89″
C	Large Cypress Tree approximately 95 m at 217°30′ magnetic from Bench Mark M-76	1 155 034	474 129	36°36′03.46″	121°52′44.23″
D	Large Cypress Tree with orange marker near sea water tank on Naval Postgraduate School Property	1 155 883	474 196	36°36′04.38″	121°52′33.85″

A grid of 12 poles (Figure 4) on the Naval Postgraduate School beach property provided a large combination of range lines that intersected the transect lines. The poles were marked by a distinctive number at the top. The specific combinations of these numbered poles used as range lines for each station are listed along with the positions of each of the 15 permanent stations in Table 2. Two additional poles immediately shoreward (approximately 40 m) of pole number 9 also served as range line markers. These poles separated by only about 3 m were designated as East Twin Pole (ETP) and West Twin Pole (WTP). Several charts and maps were used to establish

Table 2

Transect Station Positions and Pertinent Station Information

Station	Pole Intercepts	Plane Coordinates Lambert Projection X	Y	Polar Coordinates Geographic Positions Latitude	Longitude	Water Depth at MLLW (Meters)	Sediment Thickness (Meters)
A1	4-9	1 152 928	474 602	36°36′07.51″	121°53′10.23″	4.5	>2.9
A2	3-6-9	1 152 928	475 344	36°36′14.85″	121°53′10.49″	7.9	0.8 to 1.3
A3	6-ETP	1 152 928	476 003	36°36′21.36″	121°53′10.70″	10.5	0.6
A4	3-10	1 152 928	476 740	36°36′28.64″	121°53′11.01″	14.5	0.9 to 1.1
B1	4-9	1 153 996	474 574	36°36′07.55″	121°52′57.12″	5.0	1.5 to 2.4
B2	4-7-10	1 153 996	474 963	36°36′11.40′	121°52′57.26″	8.2	0.0 to 0.3
B3	6-ETP	1 153 996	475 580	36°36′17.50″	121°52′57.49″	10.4	0.0 to 0.7
B4	3-10	1 153 996	476 057	36°36′22.21″	121°52′57.66″	12.5	0.0 to 0.06
C1	4-7-10	1 155 034	474 666	36°36′08.77″	121°52′44.43″	3.0	1.9
C2	4-11	1 155 034	475 200	36°36′14.05″	121°52′44.62″	8.8	0.0 to 0.2
C3	2-9	1 155 034	475 650	36°36′18.50″	121°52′44.79″	10.4	0.0 to 0.03
C4	9-WTP	1 155 034	476 020	36°36′22.15″	121°52′44.92″	12.6	0.0
D1	2-9	1 155 883	475 102	36°36′13.33″	121°52′34.18″	7.2	0.6 to 2.5
D2	3-7-11	1 155 883	475 637	36°36′18.05″	121°52′34.38″	9.8	0.0
D3	2-6-10	1 155 883	476 245	36°36′24.63″	121°52′34.60″	12.1	0.0 to 0.3

transect anchor points, numbered pole positions, and ultimately the plotted station positions. These are on file in the Department of Oceanography, Naval Postgraduate School, Monterey. Both Lambert conformal plane co-

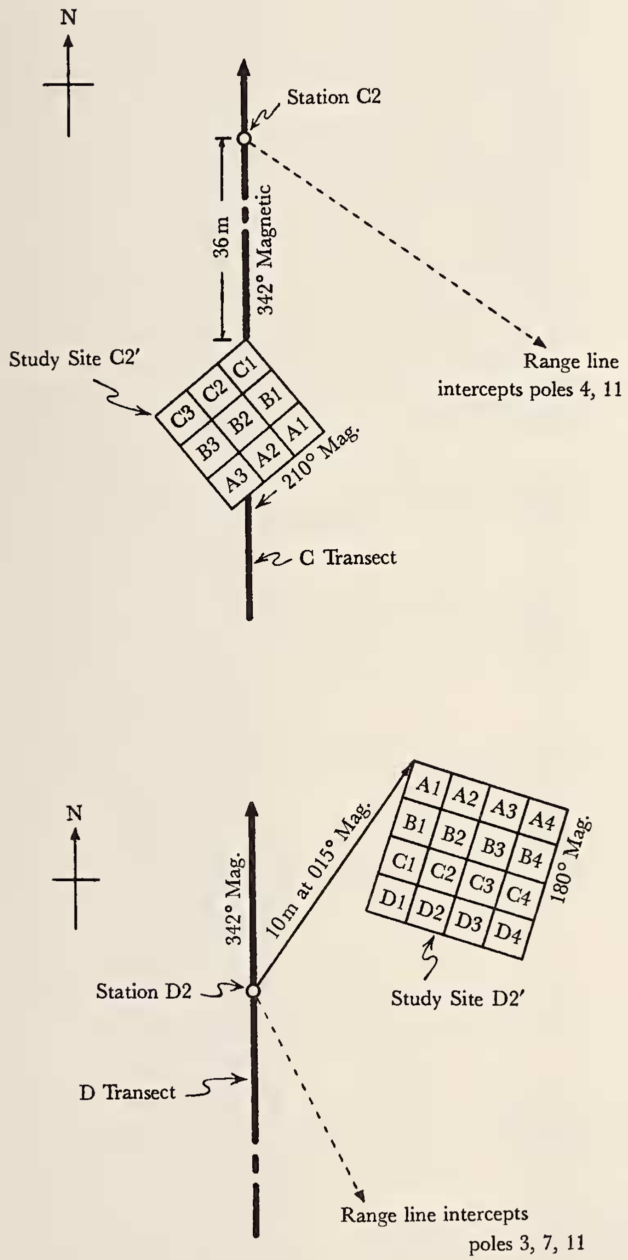


Figure 5

Orientation and Positions of the Study Sites C2′ and D2′ Grids relative to Transect Stations C2 and D2

ordinates and geographic polar coordinates have been tabulated (Tables 1 and 2) to accuracies of 1 m so that station positions may be located to the desired accuracy on any type of chart or map of the area. Each of the 15 designated stations on Transects A, B, C, and D were visited repeatedly to collect sediment and benthic fauna data. Wave, temperature, pholad and epibenthic data were obtained from a few specific locations within the study area. Wave data were recorded with a pressure transducer located between Transects C and D approximately 150 m offshore. Daily surface water temperatures were taken from Monterey Municipal Wharf No. 2 on the outside corner approximately $\frac{1}{3}$ distance from the outer end of the wharf.

The distribution of boring pelecypods was studied along Transects C and D but did not include the entire transects. The areas of Transects C and D studied in detail are shown in Figures 12a and 12b. While being studied each subtransect had a carefully measured and marked length of 6.4 mm diameter yellow polypropylene line anchored to the substrate as a reference line.

Study Sites C2′ and D2′ (Figure 5) were investigated to determine the distributions of faunal and floral assemblages associated with the rocky substrate in the vicinity of Transects C and D. When selecting Study Sites C2′ and D2′, an attempt was made to choose an environment that included as wide a range of species as possible within a workable size area while still maintaining close proximity to the nominal station locations. Therefore, Study Sites C2′ and D2′ are short distances away from Stations C2 and D2. Figure 5 illustrates the precise location of the sites with respect to the established transect stations in addition to the geographic orientation of each site. Once the study sites had been selected they were permanently marked on the bottom to permit long-term relocation, and temporarily marked on the surface to aid divers during the period of study.

METHODS

Our basic objectives were to make a detailed study of the nature of the bottom and sediments in the study area and to identify, quantify and map the distribution of the major macroscopic benthic organisms at specific stations and study sites along or near the established transects. The term "macroscopic" is used here to denote those species of animals and plants that can be observed, identified and studied by a SCUBA diver with reasonable ease under conditions of only moderately clear water, and those from soft sediments that are held back when sediment is washed through screens with a minimum mesh size of 1.0 mm.

a. Environmental Monitoring: Temperature and Wave Action

Sea surface bucket thermometer temperatures (SST) were taken daily off Monterey Municipal Wharf No. 2 throughout the period of the study. These detailed temperature records are on file at the Naval Postgraduate School. Monthly temperatures are summarized from 1971 through 1973 in Figure 6. The monthly range of temperatures from minimum to maximum is represented by vertical bars. The SST were not taken at a consistent time during the day and may be higher or lower at different hours of the day. Therefore, the observed maximum and minimum values in Figure 6 are conservative estimates of the actual maximum and minimum sea surface temperature for any month. All daily sea surface temperatures for each month were averaged, plotted and connected by straight lines to represent average yearly temperature curves.

The Naval Postgraduate School maintains an *in situ* wave sensor located midway between Stations C2 and D1 in 8 m of water (Figures 3 and 4). When operating correctly this sensor transmits continuous wave data via an underwater marine cable to a recorder on shore. The format of the wave recording system permits wave height calculations at 6 hour intervals. Approximations of 1/10th highest wave heights (the largest waves making 10% or 1/10th of a 20 minute wave record, averaged) were calculated and plotted 4 times daily (every 6 hours) in scatter diagrams for 1972 and 1973 (Figure 7). Gaps that occur in the data were due to system malfunctions. Figure 7 shows the general annual trends of wave activity within the study area, sporadic periods of extreme wave activity within the area, and actual 1/10th highest wave heights only at the location of the wave sensor. These data are not representative of the 1/10th highest wave heights along the open (exposed) Pacific coast or throughout the entire

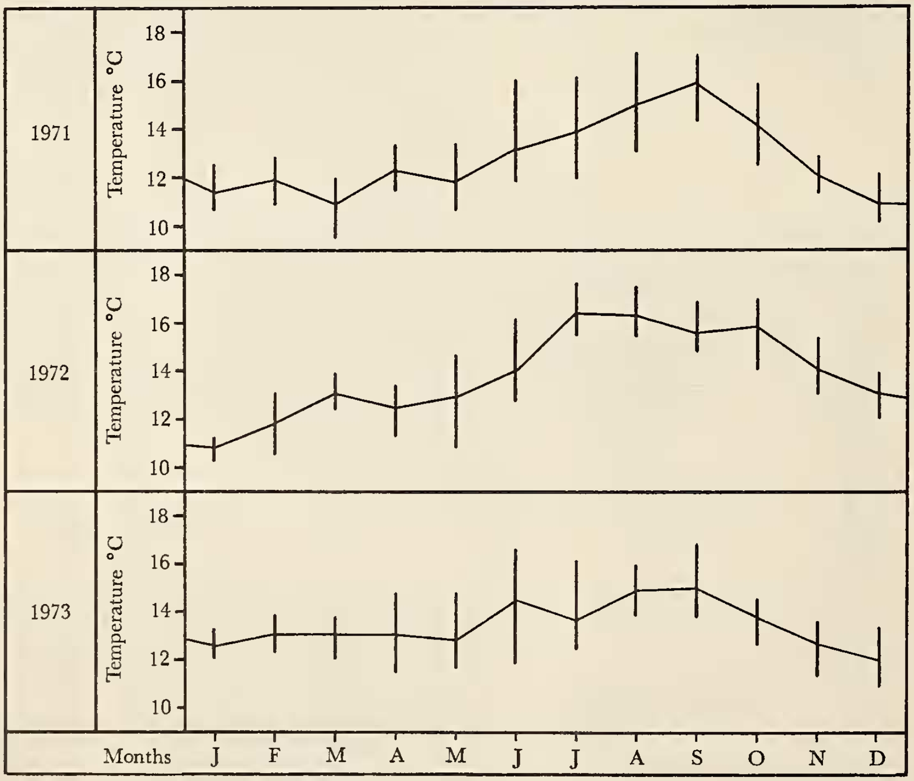
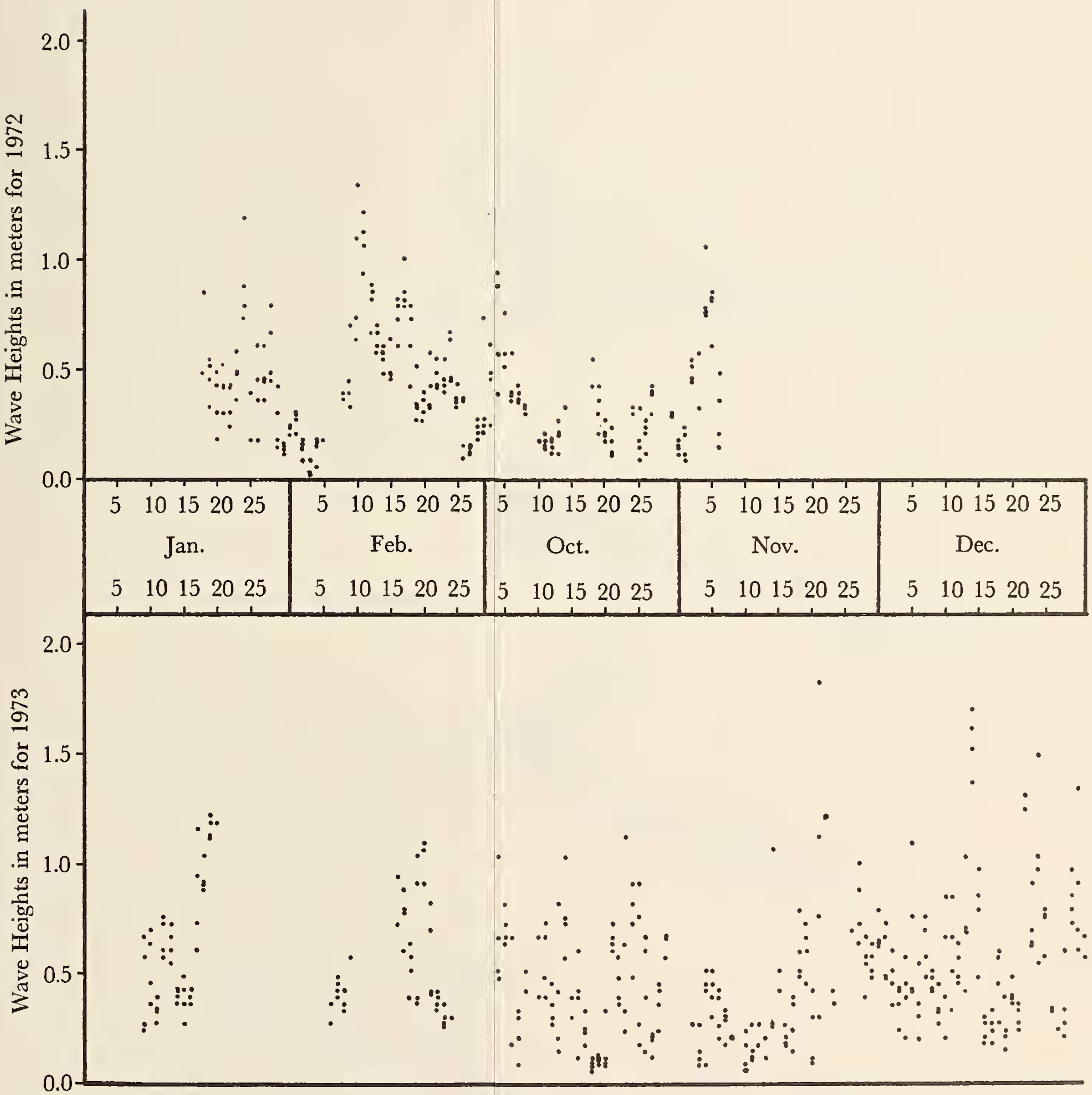


Figure 6

Summary of Surface Water Temperature in Monterey Harbor from 1971 through 1973

Vertical bars indicate monthly range of temperature; connecting lines indicate monthly average temperature



Figuvals plotted daily)

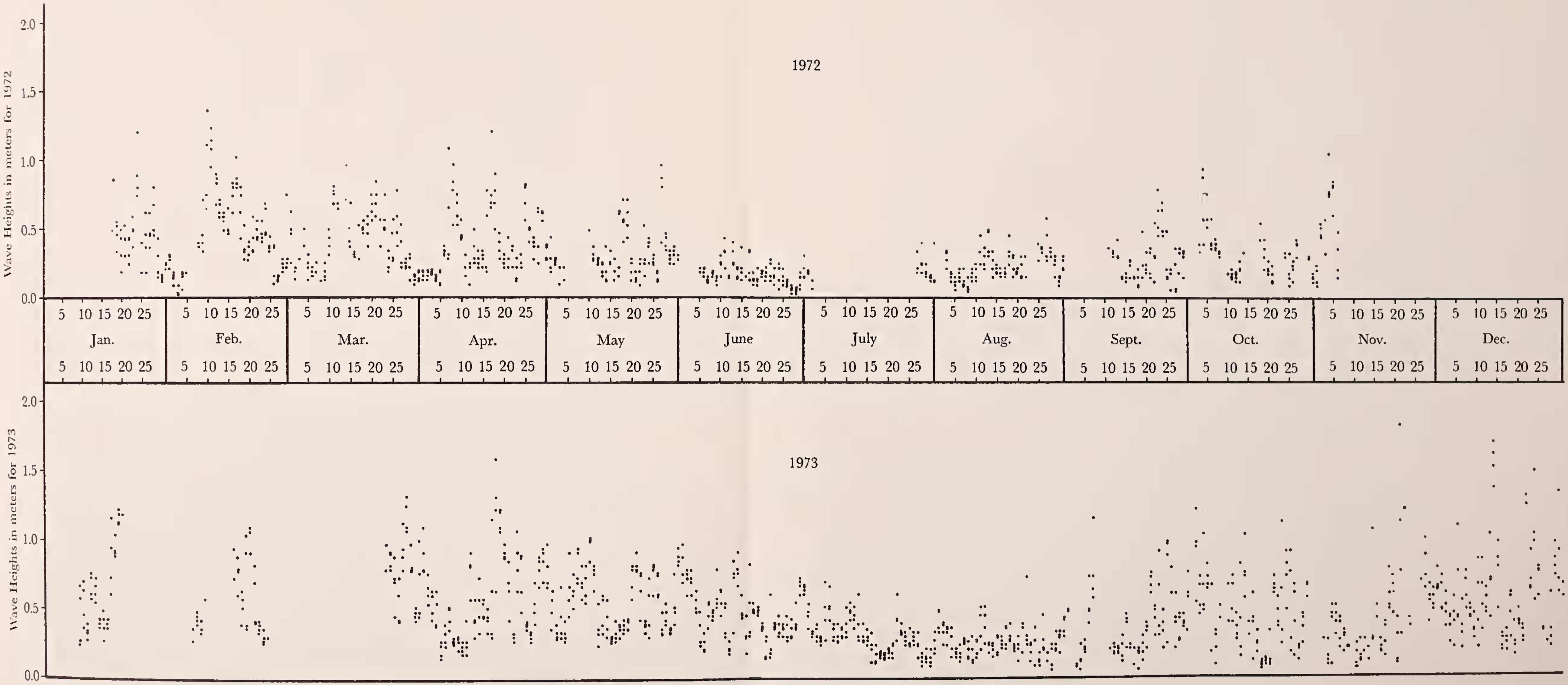
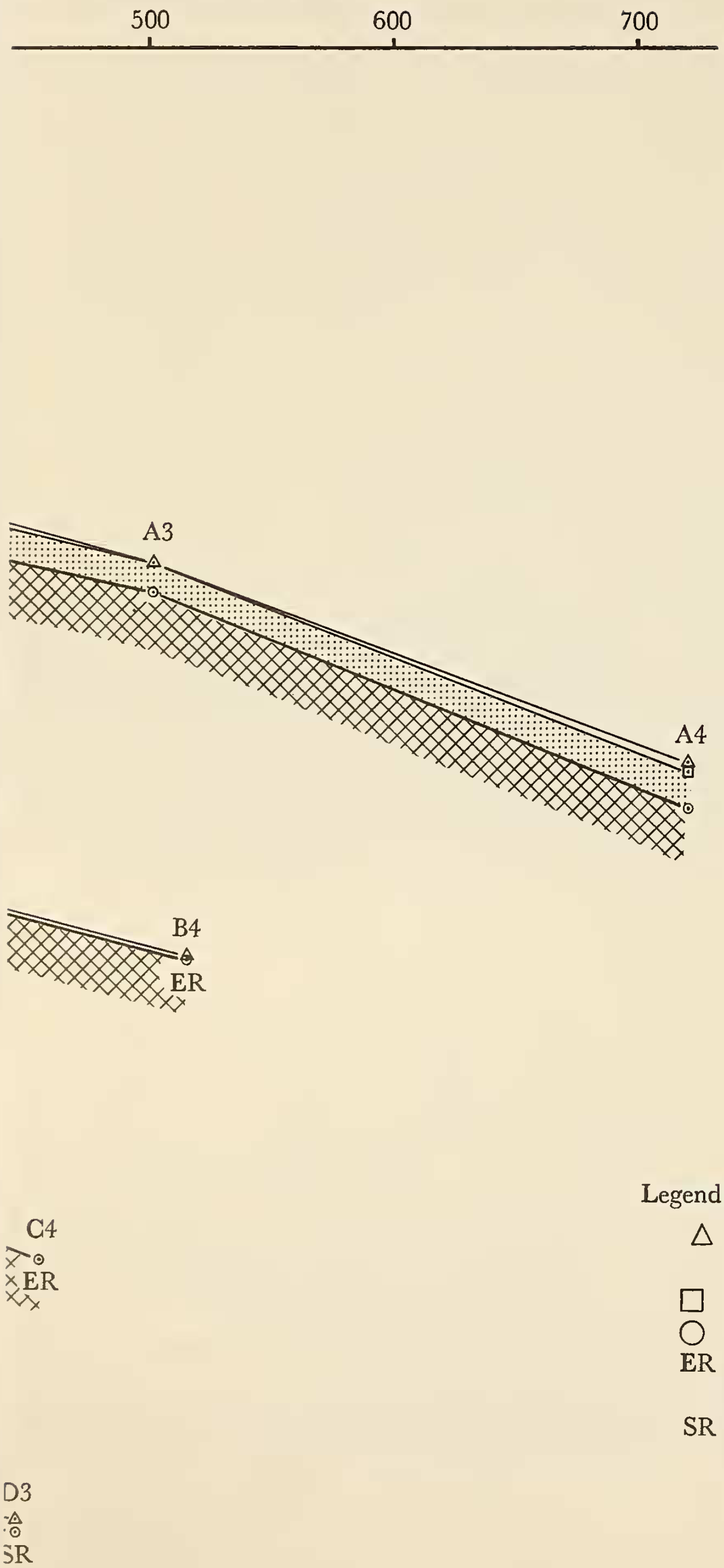


Figure 7: Scatter Diagram of Wave Heights at Wave Recorder in Study Area for 1972 and 1973 (1/10th highest wave heights at 6 hour intervals plotted daily)

W Contour on Del Monte Beach



Legend:

- △ Maximum observed sediment level or sole sediment measurement
- □ Minimum observed sediment level
- ○ Foundation rock interface
- ER Large percentage (over 50%) of rock exposed all of the time
- SR Some (less than 50%) rock outcrops exposed all of the time

epths, sediment thickness, and depths to foundation rock)

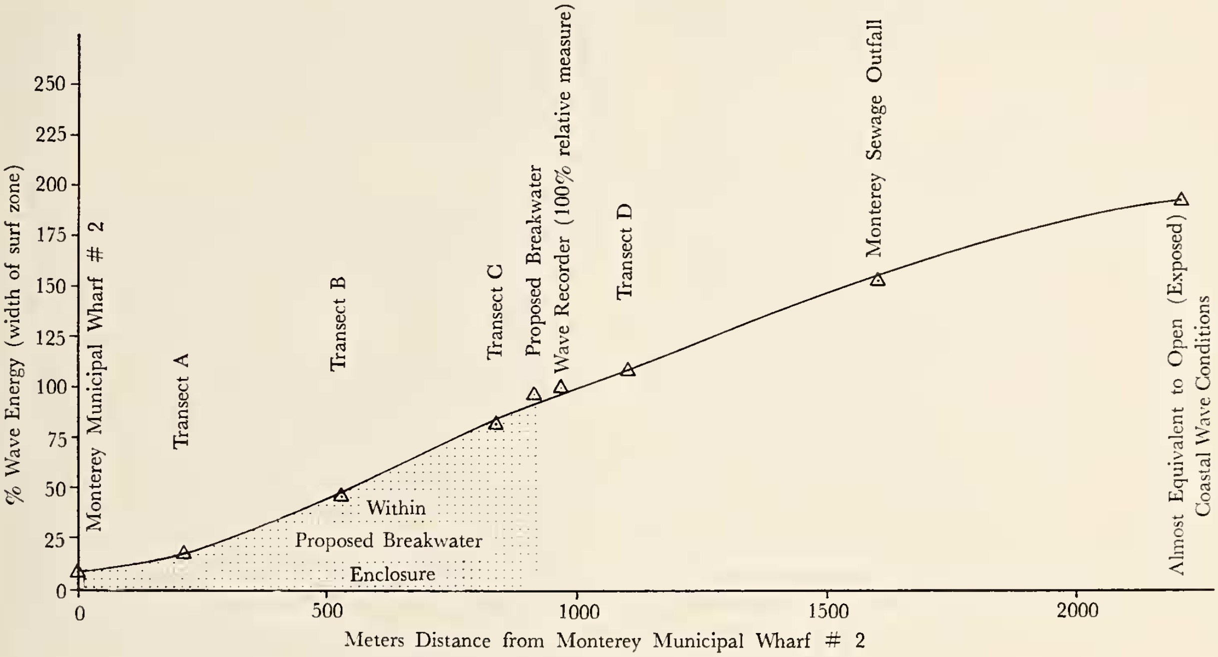


Figure 9

Wave Energy (percentage relative to wave recorder position) Imparted to Beach

area of study. Wave heights are significantly lower toward the present harbor area and increase to approximately open coast conditions 2.5 km away from Municipal Wharf No. 2. The wave heights and energy are diminished within the study area due to wave refraction. Figure 9 shows the reduction of wave energy striking the beach as one approaches Wharf No. 2 from upcoast, where wave energy and heights are similar to unrefracted wave conditions along the exposed Pacific coast. These approximations were computed from aerial photographs taken along the study area by Naval Postgraduate School personnel during January 1971. The photographs were scaled off in meters of distance (0 to 2 300 m) from Municipal Wharf No. 2. The width of the surf zone, increasing with distance from the wharf, was measured out to 2 300 m distance. Beyond 2 500 m distance from the wharf no appreciable change in width of the surf zone was noted. The wave recorder was used as a unitary reference point, where the width of the surf zone was considered to be 100% (Figure 9). Toward Wharf No. 2 the surf zone decreases to less than 10% of that found at the wave recorder, while moving away from Wharf No. 2 the surf zone increases to almost 200% of that found at the wave recorder. A section of beach with uniform wave activity (*i. e.*, no wave refraction) but with an increasing beach slope would tend to have slightly decreased surf zone width. Del Monte Beach does tend to steepen slightly ($\leqslant 5°$) away from Wharf No. 2. Therefore, the surf zone width percentages used in Figure 9 are probably conservative estimates of the variation in energy imparted to Del Monte Beach by waves.

b. Bottom Profiling and Sediment Thicknesses

During January 1971, December 1971 and April 1972 the water depths and sediment thicknesses at each of the stations were investigated. A 4 m skiff with a portable fathometer was used for bottom profiling. Each transect was profiled from the deep water station to a point as close as possible to the breaking waves near the beach. Depths at each station were checked with a lead line. All water depths were corrected to mean lower low water (MLLW) tide datum. The sediment thicknesses were measured (up to 2.9 m thickness if penetrable) with an extendable metal probe which was hammered through the sediment at each station by SCUBA divers. Water depths and sediment thicknesses were measured on successive dates. The combined data on successive dates yielded estimates of changes in sediment thickness and depth from

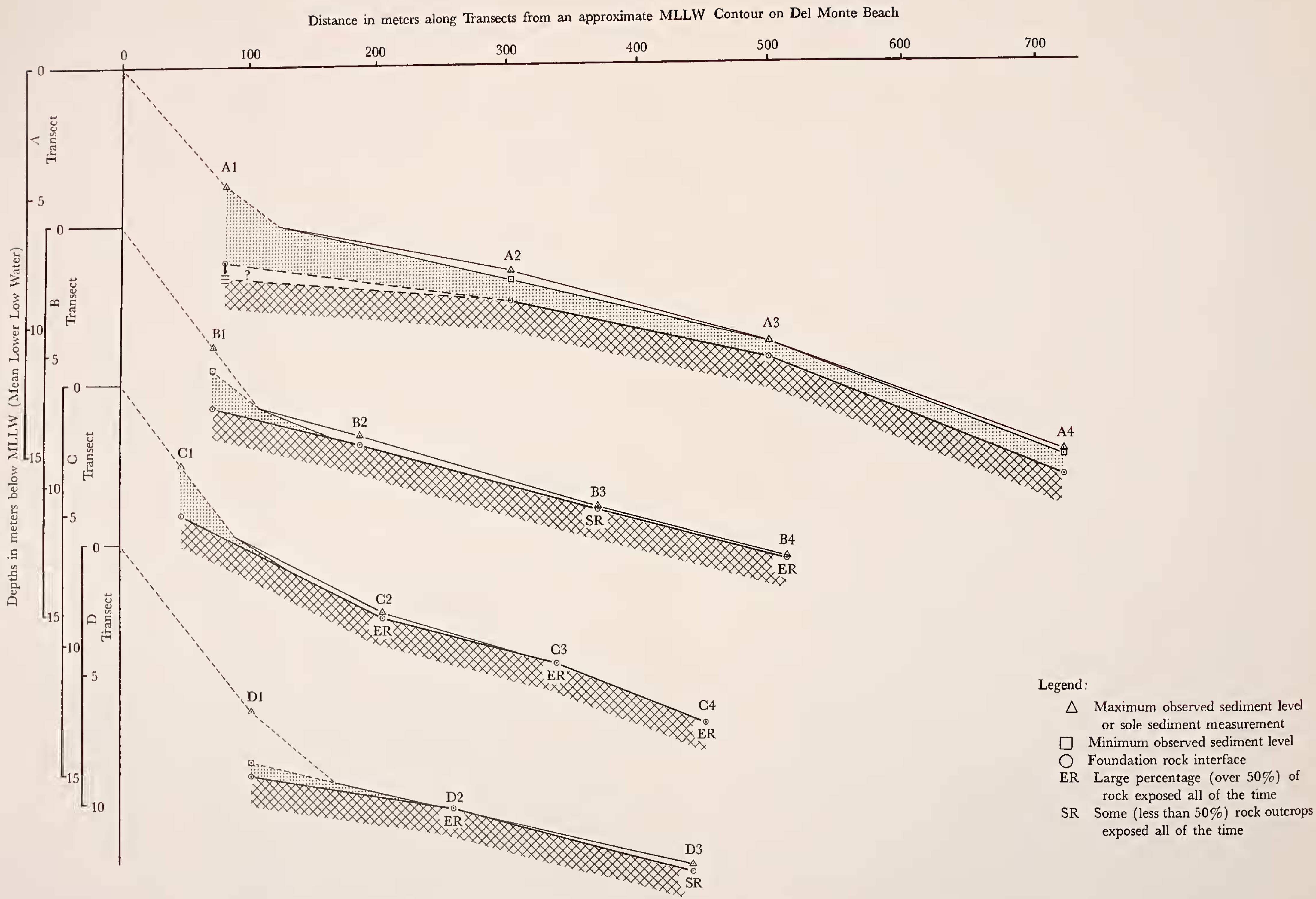
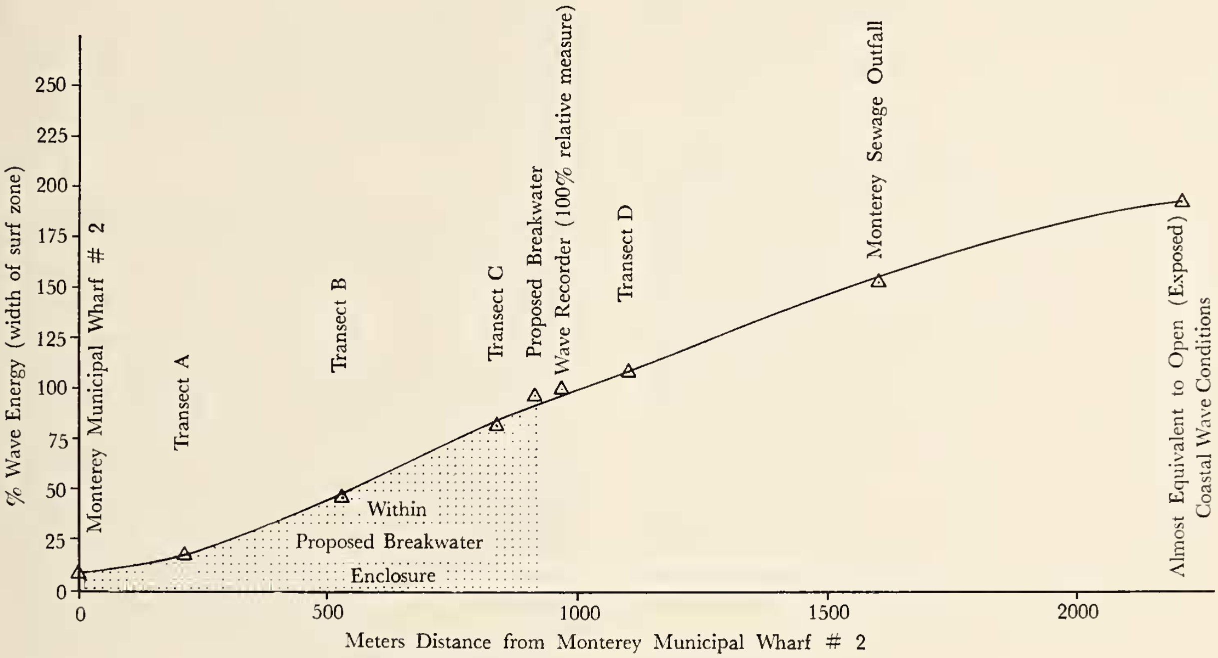


Figure 8: Transect Longitudinal Sections (bottom depths, sediment thickness, and depths to foundation rock)



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c. Sediment Analysis

Sediment samples collected at each of the soft-bottom stations were washed with fresh water to remove most of the salt water; then they were oven dried at 110° C until there was no further reduction in gross weight. While still warm, the dried samples were passed through a series of standard Tyler screens having mesh sizes of 2.0, 1.0, 0.5, 0.25, 0.125, 0.062 mm. Particles of a diameter less than 0.062 mm were collected in a bottom pan. Each fraction was then weighed on an analytical balance and the percentage of this fraction to the whole sample calculated.

INMAN (1952) and FOLK & WARD (1957) statistical parameters were calculated on the Naval Postgraduate School's IBM 360 computer. A computer program prepared by W. R. Anikouchine (DINGER, 1970) and modified slightly at the Naval Postgraduate School Computer Facility was used to calculate all the classical statistical grain size parameters. The computer program, calculated statistics and initial weight fraction data are on file in the Oceanography Department. Folk & Ward, mean, phi grain sizes will be used to describe sediment particle sizes within the study area. Sand samples were collected on 6 cruises between February 1971 and March 1973. Figure 10 represents these grain sizes averaged over the 6 sampling dates.

d. Benthic Sampling on Soft-Bottom Stations

Using our research vessels on a series of 5 cruises (11 February, 26 May, 3 November, 1971; 28 July, 1972; and 28 February, 1973), the soft-bottom stations were sampled quantitatively. Each time the ship was positioned over each station using the shore navigational aids discussed above. A modified Smith-McIntyre Quantitative Grab Sampler was used to collect bottom samples. This spring-loaded grab can bite into an area of $\frac{1}{4}$ m² and as deeply as 18 cm. On muddy substrates the grab brings up a bottom sample of up to 15 liters. When a sample from a station was brought up a hatch in the top of the sampler was opened, the quantity of sample estimated using a calibrated dip stick, the temperature of the sediment determined with a laboratory thermometer, and a 250 - 500

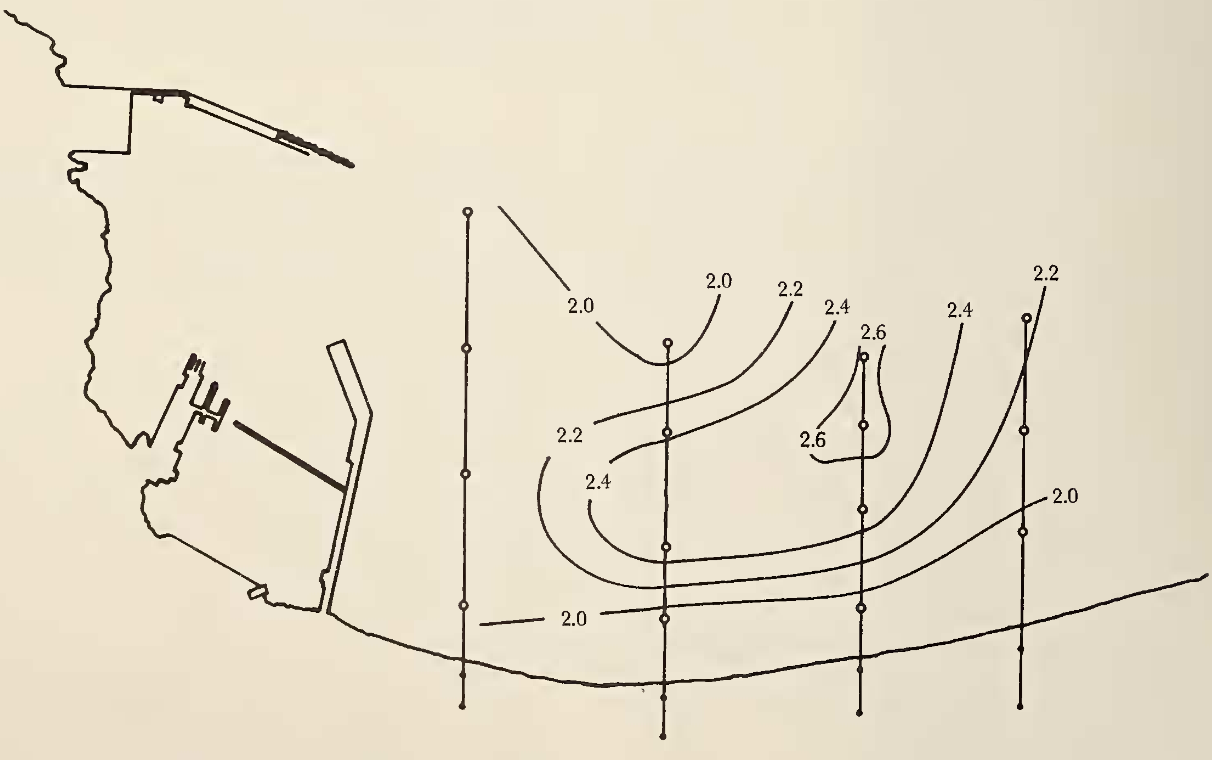

Figure 10

Contours of Sediment Particle Size (mean Phi) over Study Area